METHODS OF IMPROVING OCEAN BARS.

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In an official report on the "Brunswick Outer Bar, Georgia,"[1] the U. S. Engineer now in charge of that work presents an elaborate analysis of five methods available for creating navigable channels: (*a*) by the use of dynamite; (*b*) by a single jetty; (*c*) by a single curved breakwater; (*d*) by twin jetties; and (*e*) by dredging; from which he concludes that the last is "probably" the most economical and hence he recommends that "the Government should own and operate such sea-going dredges as are necessary and not call upon contractors for such work at all."

Inasmuch as the history of maritime works is replete with the failure of dredging machines to create and maintain deep channels in the open ocean and that the analysis and conclusions as to the methods are so erroneous as to facts and results, the writer feels impelled, in the interest of the public service, to submit a brief review of some of the cases cited therein, with a view of bringing out the truth more clearly.

1. Dynamite.

On this subject the author of the report, although having had no experience in the use of dynamite, concludes as follows:

"Fourth. The channel produced (at Brunswick, by use of dynamite) has no advantage of permanence over a dredged channel of similar size and location, which could be produced for about one-twelfth of the cost of the present channel." The unfortunate part of this comparison and assertion is that the "channel produced" is the result of dynamite aided by dredging, and is not therefore such a channel as might have been secured by dredging alone, for it is a curved channel with flat slopes constructed by aid of natural forces and which is larger than the channel contracted for and unusually permanent. None of these things would be true of a dredged channel in the open sea, unprotected by jetties or regulating works. As no dredged channel of similar size and *location* exists as a basis, no comparison can be made as to cost at this site; but a thorough analysis of other efforts to secure deep channels elsewhere shows that this effort of the contractor has been far less expensive, both for

[1] See Document 355 H. R., 56th Congress, 2d Session.

construction and maintenance, than any or all other methods attempted by the Government, as the accompanying statement, compiled from official statistics, will attest. An inspection of this exhibit will show that the cost per foot of depth gained at six other ocean bars ranged from $166,000 to $893,000, the average being $468,560, so that the cost at Brunswick is only about *ten per cent.* of that at other points where large annual expenses are still required for maintenance.

The work at Brunswick was undertaken by a private citizen of that place, at his own risk and expense, under contract with the Government for payments only after the results were secured, in order to save the commerce from annihilation. The officer in charge states that to build there a pair of "high tide jetties which might be expected to create and maintain an ample channel would be prohibitory. Jetties to low tide could be expected merely to preserve the channel location and reduce the cost of dredging. The estimated cost of these is $2,829,608. The interest on this sum at three per cent. would be $84,888.24 per annum, or probably much more than enough to create annually, by dredging, the channel depths and widths required by the act."

In a subsequent part of his report the officer in charge estimates that the requisite channel could have been created by removing 125,000 cubic yards at a cost of only $18,750. It may well be asked why this discovery was not made and applied at an earlier date and the $253,646 already paid the contractor for his channel, secured after seven years of labor, have been saved.

While this conclusion leaves the whole matter of cost problematical and guarantees nothing, it also assumes that low tide jetties would fix the channel and reduce the cost of dredging, whereas the result would be to admit and impound the littoral drift between them and so increase the amount to be removed if it did not entirely obliterate the channel, as has happened at Cumberland Sound, immediately to the south, where this plan was tried by his predecessor and signally failed. But if the cost of maintenance were even as low as $60,000, this at three per cent. would represent $2,000,000, and the single reaction breakwater could be built on this bar for less than half this sum, which would create and maintain the channel; but the author of the report dismisses this method with the remark that its theory is "fatally defective," and further that the breakwater at Aransas Pass built on this plan "is not located according to

COMPARATIVE STATEMENT SHOWING COST OF OUTER BAR DEEPENING PER FOOT UPON OCEAN BARS ON THE GULF AND ATLANTIC COASTS AS COMPARED WITH SUCH COST AT BRUNSWICK, GEORGIA, PORTS BEING TAKEN FOR COMPARISON WHICH ARE STRICTLY OCEAN BAR, AND NOT AS AT SAVANNAH AND MOBILE, WHICH ARE MAINLY RIVER IMPROVEMENTS; ALSO COMPARATIVE COST PER FOOT, WITH COST ESTIMATED BY THE GOVERNMENT FOR THE OUTER BAR OF BRUNSWICK, GEORGIA.

NAME OF OCEAN BAR.	Estimate of cost per foot by the Chief of Engineers approving Carter's recommendation.	Actual cost per foot of depths obtained.	Total of appropriations for the improvement.	Total estimated for the entire improvement by Chief of Engineers.	Total commerce of each port for 1897, as shown by Chief of Engineers' Report for 1898.	Number of feet of depth estimated for by Carter or engineers.	Number of feet of depth procured and for Brunswick certified.	Time work has continued on bar—years.	AUTHORITIES REFERRED TO. — Chief of Engineers' Reports and R. and H. Acts.	REMARKS.
Brunswick, Ga. . .	$339,750	$45,293	$253,646	$2,718,000	$18,385,224	8	5.6	7	Special Report O. M. Carter to 51st Congress; R. and H. Acts, 1894–'6; Report Chief of Engineers, 1898, p. 1317.	The average cost per foot at the six ports other than Brunswick is $468,560, or more than twice as much for one foot as is appropriated conditionally for seven feet at Brunswick, or, if paid for at same rate per foot, it would make the seven feet at Brunswick cost $3,279,920. The commerce of Brunswick for 1898 is $21,433,317, and has risen by steady increases from 1895, when it was $12,295,967, all due to increased draught of water on the bar.
Galveston		652,177	8,478,300		94,596,293	18	13	28	Chief of Engineers' Report, 1898, p. 1493.	
Sabine Pass		166,375	2,994,750		2,362,542	18	18	23	Chief of Engineers' Report, 1898, p. 1482; 1896, p. 1512.	
Pensacola			650 000		8,649,532			20	Chief of Engineers' Report, 1898, p. 1397; 1896, p. 1375.	The reliance at Pensacola is upon dredging, which has been done at charges ranging from 79 cents to 10 cents per cubic yard. The engineers' reports referred to show that depths obtained by *dredging have closed up again each time after dredging.*

Charleston.		508,009	4,064,079		12,106,763	8	8	19	Chief of Engineers' Report, 1888, p. 970; 1889, p. 1150; 1896, p. 1189; 1898, p. 1283.	The statement of commerce for Charleston probably excludes domestic imports and exports, and this may also be true at Pensacola. The statement at other ports of commerce is of imports and exports, foreign and domestic. If so, Charleston's commerce should probably be much larger. In 1896 the reported value of exports and imports, foreign and domestic, were $70,247,003. There has probably been a falling off, but not so great as figures given indicate.
Winyaw Bay. . . .		377,050	2,428,749		5,817,950	8	3	12	Chief of Engineers' Report, 1885, p. 1164; 1889, p. 1114; 1894, p. 1059; 1895, p. 1349; 1896, p. 1165; 1898, p. 1272; R. and H. Acts, 1896.	
Mouth St. Johns River, Fla		214,000	1,617,000		9,089,150	9	7	18	Chief of Engineers' Report, 1896, p. 1305; 1898, p. 1327.	
Fernandina or Cumberland entrance .		893,750	3,307,500		7,942,192	8	2	18	Chief of Engineers' Report, 1898, p. 1323; 1896, p. 1289; R. and H. Acts, 1896.	The channel sought by construction of jetties, between the jetties, does not exist at all. A large portion of the area between jetties is bare at low water. The only channel to sea is broken directly through the south jetty, and the two feet of increased depth is there only a part of the time.

the theory," although admitting that beneficial results have followed its construction. In the large space which he devotes to its discussion, he unwittingly shows that the theory and its application are entirely misunderstood by himself and others who have attempted to apply it at other places, and that great waste to the Government has resulted from a misconception of local physical conditions.

2. The Single Jetty.

It is generally believed that to protect an area from material moving in a given direction it is necessary to place a barrier on the near side of the area, or *between it and the source of the drift*, to arrest it on the "windward" side. This is the common practice on our western prairies to defend the railroads from prevailing winds and snowdrifts, or along our seashore drives to keep the sand out. To place the barricade on the far side would result in rendering such thoroughfares impassable or greatly increase the cost of maintaining traffic. Precisely the same laws obtain in sand driven by ocean currents or waves, and yet it appears that almost invariably and with numerous precedents as a guide the jetty is placed on the *far* or wrong side of the channel to be created, where it invariably chokes it up and results in pushing the bar seaward, giving no beneficial result from the natural energy and adding greatly to the cost.

For example, this report says that a single jetty projecting from shore to fix the channel and prevent a considerable escape of the tidal flow should be placed on the *leeward* of the channel, or "upon that side of the channel toward which the latter is being driven by the drifting sands," and it adds, "This principle of construction was first suggested by Major Thomas W. Symons, Corps of Engineers, U. S. Army."

The Major will hardly claim the honor of so serious a fallacy, since a jetty so located was suggested by a former Chief of Engineers, now deceased, for the improvement of *Aransas Pass* and was partially built by the district engineer in the years 1885–90, but it merely intercepted the littoral drift moving southerly, dropped it in the channel which it obstructed and pushed the bar seaward with a consequent loss of depth. It cost nearly half a million dollars and was an acknowledged failure. It furnished a complete demonstration of the falsity of the theory of attempting to create a channel by placing a jetty to "leeward of the channel."

This experience should have sufficed, but it did not, as the same error was repeated at *Galveston*, where for many years an effort was made to create a channel by building one jetty on the "leeward" side of the channel which it closed by a shoal, and which rolled the crest of the bar about three miles farther into the Gulf and with no increase of depth. It was only after the windward jetty was built which partially arrested the drift that dredges were enabled to make any material impression on the depth.

In this single instance, the repetition of this error in the order of construction has increased the cost of the work more than $6,000,000, and yet, notwithstanding the freqnent discussions of this subject, it does not seem to have been sufficient to have been convincing, since it is again seriously recommended to repeat the mistake by locations made on the "leeward" side of the channel, and the success which has attended the opposite location is pronounced "fatally defective."

Moreover, it is true that several jetties have been partially constructed on the Pacific coast also based upon this erroneous idea, that the best way to create a channel was, first, to dam it up by a jetty to leeward and then to dredge it out, as the sequel will show.

The report says (p. 19), "A single jetty at *Coos Bay*, Oregon, has been built in accordance with this theory and appears to have been successful in increasing the depth from ten feet to not less than eighteen feet, which latter it has maintained for the last five years."

Unfortunately for this alleged increase of eight feet, caused by a jetty built to leeward, upon which reliance is placed to prove the theory, the official records of the Reports of the Chief of Engineers show that the natural depths prior to the beginning of the work were at one time twenty-seven feet,[1] while the latest report gives the depth as ranging from eighteen to twenty-two feet and the map shows the limiting depth to be nineteen feet, or a loss of eight feet instead of a gain, thus disproving the theory of the leeward jetty, as in

[1] See Report, 1892, p. 2673: "Capt. Magee states that the best water and safest channel is always found when the channel across the bar is in its most southern position, *i. e.*, about 500 or 100 feet south of the present position of the bar buoy. It is safest because it affords the shortest and most direct route to the sea, and enables a vessel generally to take the swell head on, or nearly so. At one time when the channel was in the above position there were twenty-seven feet at low water across the bar."

other cases. This single jetty is, however, but the incompleted part of a twin jetty project and hence was not designed to operate as a single reaction jetty at all. The total appropriations were $888,750, while the estimated amount to complete the twin jetties to secure twenty feet is $1,791,412.20; total, $2,680,162.20. The bar is moving seaward at a more rapid rate than ever, and is now about 1800 feet beyond the jetty. Its average rate is 200 feet per annum.

The question may well be asked, Why build this second jetty, at so great cost, if the depths are already over twenty feet, and if dredging is so much cheaper? The map however shows why, since a sand spit extends from the southerly side of the channel to beyond the end of the north jetty and the bar is 1800 feet beyond the end of the work. The crossing is north of the jetty which extends straight out from high water mark. In the writer's opinion, had the south jetty been built first the north one could have been greatly shortened, or possibly omitted altogether.

The low tide jetty at the mouth of the *Columbia river*, to which reference is made, although placed on the windward side of the channel with reference to the littoral drift, was not built high enough to intercept that movement, neither was it curved in the right direction to control the ebb reaction, and hence it followed that during the time while the groin was filling the bar deepened, but as soon as this was accomplished and the drift could travel over it, the bar again retrograded and a further extension of over four miles is required to catch up with the advancing bar. This jetty has cost $1,965,022.76.

The last annual report (1900) says, "The result of the survey shows a decrease in depth of from four to five feet at mean low water. The greatest depth reported the previous year was twenty-eight feet. . . . . Rapid extensions of the jetty seem essential to recovering former depths." The map shows twenty-three feet on the bar.[1] The estimate for forty feet is placed at $2,531,140. It is not an illustration, however, of a jetty placed to leeward of the channel, neither is it a correct application of one to windward, as it violates the conditions of protecting the channel from the drift and of conserving the energy of the effluent stream.

Failure fully to comprehend the lessons furnished by the precedents referred to in this report results in a repetition of the

[1] Natural depths of twenty-eight feet were reported prior to 1850. *Vide* Wilkes' *Western America*, 1849, Library of Congress.

unwise recommendation that "A single jetty on this principle at Brunswick would be located on the south side of the channel, since the drifting sands come from the north."

Such a location, if followed, would in the writer's opinion be ruinous to the commerce of that port. Its estimated cost is $1,517,798.

It is certain that it would dam up the channel and push the bar to the sea with the same or less depth than previously existed, as happened to the Government plans at Aransas Pass and Galveston during construction, also at *Cumberland Sound* where the south jetty, projecting to leeward, has entirely obliterated the old channel and made it necessary to open a new one by dredging away a part of that jetty and opening a passage to a new crossing under its lee. This experiment, as shown in Senate Document No. 163, Fifty-fifth Congress, First Session, should have sufficed to illustrate completely the results to be anticipated from such a proposition for Brunswick, where, it is stated, there "is an enormous sandbank which moves and which always moves very positively in one direction."

So pronounced was the failure at Cumberland Sound, after twenty years of study and experiment and the appropriation of $1,787,500, that in 1897 Congress called for a report to ascertain whether an emergency appropriation should not be made "to protect the entrance from being closed against commerce." In the report made in pursuance of the resolution, the officer then in charge stated: "The navigable bar channel has deserted the desired route entirely, the present channel crossing the south jetty about 7000 feet seaward of its initial point." Also the bar crossing is now "nearly half a mile south of the outer end of the jetty" and the "least depths are somewhat less than thirteen feet." This was the natural depth. The comparative maps in this report show that instead of the channel remaining in its original position as it should have done, according to the theory of the author, it was actually driven across the intercepting jetty and sought its normal position along the line of least resistance in its lee, thus bringing the jetty to windward, where it should have been placed at first.

Thus Nature would teach Science, if the latter would but learn to interpret her results correctly. A more complete illustration can hardly be found of the soundness of the theory of interposing the barrier between the channel and the advancing drift, or to windward and not to leeward. Here where a jetty was built to leeward, according to the author's ideas, the natural forces changed it to windward by shifting the channel to the opposite side—a complete demonstration in his own district.

The report also shows that a deep and narrow channel is anticipated on the windward side of the jetty, for it says:

"It is difficult to see how such a constant force from the north could avoid crowding the channel close to the jetty and making it sufficiently deep near the latter torequire extensive and expensive work to prevent undermining."

The results, however, are just the reverse of this as seen at Cumberland Sound, for the sand being heavier than water, when it meets with an obstruction is dropped in the channel, if to windward, and fills it up. Yet notwithstanding these years of experience and expense at Cumberland the report states: "The jetties so far constructed at Cumberland Sound have not yet progressed sufficiently far to have much influence upon the bar depths."

On the contrary, the author might have said with more truth, they have had so great an influence upon the bar depths as to have entirely obliterated the old channel, and to have created a new one which now crosses the south jetty through the breach made to admit light draught vessels to the port. The depth has not been increased.

A somewhat similar experience occurred at Manasquan inlet on the New Jersey coast, where the jetties were completely buried under a sand bank and appropriations were requested to remove the obstructions. These lessons of experience are lost upon a constantly shifting personnel and they have cost the Government much time and money, whereas the bar depths have not been materially increased by the application of natural forces. In recent years, by localizing the channel at the mouth of the Columbia, there was a temporary gain of about four feet at a cost of $500,000 per foot; and at Galveston of thirteen feet, mainly by dredging, costing nearly $700,000 per foot to date. The total expenditures by the Government on its works at Aransas Pass, Galveston, Coos Bay, Columbia Bar, Cumberland Sound, St. John's River and Gray's Harbor, where in most cases the leeward jetty was built first with injurious results, have been about seventeen millions of dollars ($17,000,000) and still the same method is urged as being the proper policy to pursue.

3. "The Single, Curved Breakwater."

The report next analyzes the reaction breakwater partially built by private capital at Aransas Pass, stating some of the requirements it was designed by its inventor to fulfill, namely: (1) It must be located on the windward side of the channel. (2) It must be detached from the shore to admit the full tidal prism. (3) It must produce a continuous reaction across the bar by its curved trace.

Another requirement, which the author professes not to understand clearly, is that "the breakwater has to be curved to produce reactions similar to those found in the concavities of streams and having radii sufficient to maintain channels of the requisite depths;" also "the breakwater must change the conditions of equilibrium of flood and ebb currents in favor of the latter."

This last, he adds, "is too vaguely stated to admit of discussion." After stating that the first and second of the above requirements are directly contrary to each other, the author proceeds to predict what should happen, but which, unfortunately for his forecast, after some four years of exposure, has not happened. The channel has not shifted its position, there has been no dredging, nor any expenditure upon any part of the work for maintenance, and the depths have increased in the lee of the breakwater to a maximum of twenty-five and a quarter feet and a minimum of fifteen and a half feet, although large gaps were left in the breakwater at both ends when the work was suspended in 1897.

The sophistries and opinions suggested to discredit these unprecedented results are best answered by the results themselves, as the report acknowledges "at Aransas Pass to-day there is probably a minimum depth of fifteen feet with over twenty feet close to the jetty." This is therefore the admitted result, with barely half of the work contemplated in place.

The author next proceeds to show that not only is the theory defective, but that it has not been correctly applied; and to sustain this assumption he must, perforce, invert the direction of the littoral drift, ignoring entirely the former Government experience when the old curved jetty was built on the other side of the channel, and resulted in failure.

After concluding that the reaction breakwater is not built in accordance with the theory of its designer, the author then attempts to build up a case of two jetties by statements such as these:

"It seems plain that most of the operation is that simply of two jetties, one somewhat longer than the other, its curved shape possibly making up in part for the lack of length in its mate. The first of these jetties—the north one—is composed of two parts, one of which is a natural bank extending from St. Joseph's Island to the inner end of the breakwater, a distance of about 1700 feet." As there is no "natural bank" across this 1700 feet of tidal opening, where the depths are from five and a quarter to four and three-quarters and two feet at mean low water and which opening is a part of the design to admit the full tidal enegry, and as all of the inner end of the so-called jetty to a point 4000 feet from the island is below water surface, some of it as much as fifteen feet, it is difficult to accept the statement that it is part of the jetty relied upon to control effectively the ebb currents or even to arrest sand, which does undoubtedly enter the channel through the gaps to the detriment of the work (see PROCEEDINGS OF AMERICAN PHILOSOPHICAL SOCIETY, Vol. 38, Plate VII).

But the author, not appreciating fully the important function of arresting this drift, adds that "the trend of the currents is such that no artificial structure is needed here." Yet the Government Board recommends in its proposed plan to close this opening by a sill some three or more feet high. Why should it do so if not needed to control the currents, or if, as the author asserts, the sand is drifting in through this opening, why should it not be needed to arrest this movement?

The report then stated that "for a further distance east of 4650 feet we have in the breakwater itself a more or less complete actual jetty, with a little foundation beyond this."

How much is "more" and how much "less" does not appear; so that from the author's view it would seem the north jetty consists of a natural bank for 1700 feet and a more or less completed actual jetty of 4650 feet, a total structure of 6350 feet, giving the impression to one ignorant of the facts that there is a retaining wall of that length which controls the currents, whereas of the reaction breakwater, or so-called "north jetty," less than 1500 feet reach above high water, and hence for only about twenty per cent. of this entire distance are the currents under the full control of the structure.

The alleged south jetty, according to the report, is built up in a similarly ideal manner, as follows:

"Opposing this and forming the south jetty we have, first, the reveted head of Mustang Island and the old Nelson jetty, extending from the same base to a distance of about 3150 feet. Beyond that we have the old Government jetty, a submerged structure, but still a jetty capable of exercising an important influence on the tidal flow a further distance of 2350 feet, making a north jetty having a total length of 6350 feet and a south jetty having a total length of 5500 and located about 1250 feet apart."

Again, to a novice these statements are grossly misleading, since the old Nelson jetty, which was built of wooden cylinders filled with sand, was destroyed where exposed to the sea soon after it was placed, as was predicted. It long since ceased to act as a jetty (see map, Fig. 6, in the report). There has been no revetment placed on Mustang Island for more than a decade, and its outer shore line has apparently advanced between January, 1899, and May, 1900, only about 500 feet; but this was *after* the depths as reported were secured (see Maps 5 and 6), and hence could not have been instrumental in causing them. Moreover, the old Government jetty is not only "submerged" but subterranean, being buried under the sand which the reaction breakwater has thrown over it; and hence being in a region of deposit, not of scour, and being under ground, it cannot be regarded as "capable of exercising an important influence on the tidal flow" as an active agent to confine the currents, and thus the fallacy of the two jetties 1250 feet apart is reduced to the effective portion of about 1500 feet of the breakwater extending above high water and the unfinished submerged flank of the same, partially overlapping the outer end of Mustang Island, but having gaps of fifteen feet and less in depth. The sandbank on the southerly side of the channel is the dump for the material removed by the breakwater, and is the effect, not the cause, of the deepening created by it. The theory that these results are due to two jetties is wholly without foundation in fact.

Another serious error into which the author has fallen is in determining the direction of the resultant drift, which furnishes the key to the correct solution of the problem by a single jetty. He insists that all the charts which were accessible, as well as the statements of more or less interested parties, were to the effect that the resultant movement was from south to north, and that since the breakwater is on the north side it is therefore located to leeward and not to windward, as it should be according to the theory of the writer. He discusses the anemometer records, and although they show that the intensity of the northeast storms is to that of the southeast as 43.7 is to 34.2, yet because the lighter winds prevail longer from the southeast he concludes that they are the determining factors, and overlooks entirely the unmistakable record of the movements of the inlets along this coast, as shown so clearly by the comparative charts which he must have consulted in the reports to which reference is made. These show that the tall masonry lighthouse built at Aransas Pass between 1851 and 1860, and which then stood abreast of the inlet to light the channel and bar crossing, is now about two miles to the north of the present position of the inlet and its bar, so that St. Joseph's Island has been extending southward at the annual rate of about 260 feet, while Mustang Island has been receding; and as the channels do not move toward but away from the resultant, there should be no cause for doubt as to the direction of the movement, excepting to those who cannot correctly interpret nature's record.

In further support of this inversion of the facts, the statement is made that the foreshore on the northerly side of the jetty shows a loss or scour of 1,270,000 cubic yards since 1895, and that there is no indication of this material having moved seaward, nor has it gone through the opening between the breakwater and the shore into the harbor, and as it would be inconsistent for the argument to have it travel southward, he adds:

"Of course this sand cannot have gone to the south over the breakwater, otherwise there certainly would have been a fill close behind the latter," so it must have gone north, and the assumption is thus established.

Unfortunately for this argument the original compact material in place "close behind the breakwater" has been scoured out by the natural currents even to a depth of over twenty feet and close to the breakwater, as the author admits, consequently any loose sand carried over the breakwater would, *à fortiori*, be much less apt to be lodged in these currents and would be at once carried out and around the sandy spur to the southward, as has happened and as is quite evident from the comparative charts; so that the statement by the writer is true that not only has this incomplete breakwater removed about 600,000 cubic yards in place, but has prevented the deposition of a much larger amount drifting in from the north through the gaps and over the unfinished portions of the structure. This action is so manifest as scarcely to require so long an explanation, but for the misconstruction which has been put upon it. At Cumberland the drift moved over the jetty and across the new channel in a similar manner and passed on to the southward. The testimony of nature is worth far more as to facts than that of interested and superficial observers, and yet, in view of his own admission that the evidence of the northward movement "is mostly negative," the writer, to sustain his effort to condemn the theory as fatally defective and to demonstrate an error in location, must, perforce, invert the testimony of nature to accommodate a preconceived theory. (For the evidence see Doc. 137, H. R., 55th Cong., 2d Sess., Charts No. 6; survey of 1854; No. 7 of 1868; No. 8 of 1891, etc.) A superficial glance at these will show the prevailing direction of the drift and the loss of depth in the channel until improved by the reaction breakwater.

Such statements might be ignored were it not that the errors which lead to them have involved the country in such large and useless expenditures with injurious results to our commerce, and have inflicted upon us an enormous annual and avoidable expense for maintenance of channels by dredging, which the author recommends be done by day's labor and with Government plants, thus destroying competition.

Yet all this expenditure does not seem to have had even an educational value upon the author of the report under consideration, who recommends its continuance.

Hence it is not surprising, after such an ingenious misconstruction of data "mostly negative," and which makes the littoral drift come from the southwest or in a direction opposed to that of the drift of the inlet for at least fifty years, that the author reaches these erroneous

"Conclusions."

"1st. The theory of the reaction breakwater is fatally defective in the following particulars, viz.:

(*a*) It provides for no force or resistance to hold the currents against the breakwater. Such provision would usually mean a second jetty.

(*b*) Should it increase the depth, such increase is limited and beyond that an undue amount of dredging would probably be necessary.

(*c*) If successful in deepening the channel, it would probably move the bar seaward and the seaward extension of the works appear impracticable.

(*d*) It makes no provision against the channel being driven too close to the breakwater for the safety of itself or shipping, by sand coming from the opposite direction or by the current being directed against the jetty in accord with the theory.

That these opinions are hypercritical will be seen from their contradictory character, for in (*a*) it is said there is no provision to hold the current against the breakwater, while in (*d*) it is said that the channel may be driven too close by sand from the opposite direction. In (*b*) the objection is made that should an increase of depth result, such increase would involve an undue amount of dredging; or in short, although the currents scour out a natural channel, defended from the resultant sand movements by the breakwater, there would still remain a larger than before volume to be removed by dredging. (*c*) The result of any deepening might extend the bar seaward and the breakwater could not be extended.

Any material carried to the outer slope would be ejected in deeper water where the littoral current and wave action at head of breakwater would prevent its deposition, as the incomplete results have shown, and, if necessary, a considerable extension of the works seaward is quite possible without injury to navigation. The facts, however, at Aransas, as previously stated, are so confirmatory of the theory that they have been recognized by impartial juries at the Paris Exposition and the National Export Exposition as worthy of their highest awards, while the American Philosophical Society and the Franklin Institute, after thorough and extended investigations, have also granted their highest honors to the inventor.

In view of these findings of experts, it is somewhat confusing to read further in the official report of the officer in charge of the work at Brunswick:

"The only apparent example of such construction that has been tried is at Aransas Pass, and that is no test of the theory at all, as the breakwater is not located according to the theory, and the beneficial results produced are not the result of the reaction breakwater as such but by incomplete twin jetties." If such be the case, then the maritime engineers and societies who have recognized the merits and results of the incomplete work at this place must have stultified themselves, and it remains for the author of the report to cite a single instance where similar results have been secured by "incomplete (or even complete) twin jetties" in the same time or for the same cost.

As the depth entirely across the bar has been increased from six to over fifteen feet at a cost of about $30,000 per foot, with a large area having depths exceeding twenty feet, it remains a fact that there is no record known to the writer exhibiting equal efficiency and economy.

Yet the report illogically concludes from these erroneous premises and misconstructions: "For these reasons, a single reaction breakwater is not recommended for the improvement of Brunswick bar."

How groundless "these reasons" are will no doubt appear from the previous analysis, but the *primum mobile* for the failure to recommend it may be better understood by stating that for some fourteen years the attention of the Government has been invited to this improvement through its engineer officers. As long ago as the 16th of March, 1888, a Board reported to the Chief of Engineers the following conclusion :

"The views are purely theoretical, are unconfirmed by experience, and contain nothing not already well known which has a useful application in the improvement of our harbors."

The Board, however, cited no precedents, although requested to do so, and all applications for permission to make a demonstration remained unanswered.

Again, in 1890, the officer in charge of the jetties at Cumberland Sound, after mature study, submitted on his own responsibility a plan involving the use of a single, curved, reaction breakwater, properly located on the windward side of the channel, at an estimated saving of $1,108,004, of which $125,000 was for the removal of part of the south jetty, which he reported as being "improperly located." On March 11, 1891, a Board of Engineers, composed with one exception of the same officers who had made the original adverse report, stated as follows:

"The Board does not think that a single jetty on the north side of the channel, curving gently to the south, would secure the deep water needed, but is of the opinion that two jetties will be needed. . . . . The opinion that such a curved channel conforms to the natural requirements of the site and opposes the action of the natural forces less than any other, is believed to be fallacious."

In consequence, work on the two jetties was continued with the disastrous results already stated.

Again, after all former attempts to deepen the channel at Aransas

Pass had failed, and the reaction breakwater was partially built with the results given, the private funds became exhausted and the Government was asked to appraise the value of the work done, take over the breakwater and continue it immediately. A Board of Engineers reported in 1897, just after the obstructing old Government jetty had been breached, that:

"There does not seem to be any probability that the jetty as now constructed will of itself secure and maintain any considerable increase of depths in a navigable channel of proper width. The Board is of the opinion that the value to the Government of the works for the improvement of Aransas Pass is nothing."

The depth was then nine and a quarter feet. It is now fifteen feet, and as yet no work has been done, although Congress made an appropriation more than two years ago of $60,000 to remove the remains of the old jetty built across the channel and on its leeward side. This is now buried, as previously stated, by the action of the breakwater under the bottom of the channel, and is a barrier to its further deepening.

Finally comes this Report on the Brunswick Bar, which condemns the theory as well as its application as being erroneous even in the face of the indisputable evidence of nature.

These statements are made to illustrate the operation of the law of conservatism which ever attends the path of progress to retard her too rapid strides. Its consideration would divert this analysis of physical fallacies, facts and forces to the domain of metaphysics and is therefore not pursued further.

4. Twin Jetties.

This is the method most generally used in efforts to create channels and the record of their experience is quite suggestive. At the mouths of large sedimentary rivers, emptying into nearly tideless seas, they have been reasonably successful, but for tidal inlets their utility is very limited. The report says: "Apparently the only examples of high tide jetties in the United States are at Sabine Pass, Galveston, and Yakina Bay, Oregon."

This statement suggests the necessity for greater research on the part of the author, since the well-known jetties at South Pass were built above high water, as are also those at Newburyport, Mass.; New Haven, Conn.; Manasquan, N. J.; Brazos River, Tex., and at other points, while both jetties at Yakina were originally designed to rise only to half-tide, but both were subsequently raised above high water to make them, if possible, effective. It is not the purpose of this paper to review the results of works of this class, but their sequel shows that they have not fulfilled the expectations of their designers and that they have not arrested the advance of the bar seaward nor have they given the anticipated depths, with the exception of South Pass. This, however, has caused a rapid shoaling in the entire channel above the jetties in consequence of over-contraction, and necessitates the maintenance of the depths by dredging for a distance of many miles because of the elevation of the flood plane and bed of the stream by sedimentation.

Hence the necessity for an early removal of the bar at the Southwest Pass.

But to return to the discussion. The author suggests that to arrest sand movements entirely, high tide jetties are requisite, and cites those at Yakina Bay as a type, as having "increased the depth from seven to fifteen feet at mean low water, and, so far as the records show, without as yet producing any new bar seaward of the jetties." It may suffice to state, on the contrary, that while the original depths at low water were seven to nine feet, the latest annual report of the Chief of Engineers for 1900 says on p. 4298: "There is at present, about one-half mile from the end of the jetties, a crescent-shaped bar almost enclosing the entrance and having from eight to twelve feet of water over it at low water. Around the south end of this shoal there is a channel having a least depth of thirteen feet[1] at low tide. This bar has apparently shoaled somewhat since the survey of 1895." The report of 1887, when only a portion of the south jetty was built, also shows a low tide channel of thirteen feet, and the officer then in charge calls attention to the movement of the bar seaward toward a reef of rocks.

These official statements would appear to discredit the assertions of the author as to an increase of depths to fifteen feet and no advance of the bar seaward.

In commenting further upon twin jetties, the author remarks: "Jetties built to a height sufficient to stop the sand flow from both sides and also high enough to control the tidal flow should be expected to reproduce at the bar the depths at the gorge." Experience does not seem to confirm this expectation, since nature fur-

[1] The chart shows but ten feet. This may be an error, however.

nishes no illustration of a deep pocket at both ends of a contracted pass, whether natural or artificial. High tide jetties, unfortunately, greatly obstruct the ingress of the tides and hence reduce the volume available for ebb scour, and it was to meet this condition that the reaction breakwater was, in part, designed with such marked results.

The former method proposed for overcoming this objection was, as the author states, to increase the width between the jetties on the bar and to build them only to near low-water mark, but, as he adds, the scouring effect has not produced depths great enough for navigation—although "dredged channels can be maintained at comparatively moderate cost," as at Charleston, which is cited as "a good example."

Here, again, it would seem that the reference is unfortunate, inasmuch as the Government dredge was unable to maintain the channel on the ranges, and a new and more powerful machine is building, while the bar has reformed three-quarters of a mile beyond the jetties, and the outer twenty-six-foot contour is 1.5 miles to seaward of them. The jetties were reported completed several years since, at a cost of about $4,000,000, but they have failed to hold the bar, which has eluded them and gone to sea, where dredging is now required in open water. The author recognizes this feature in his report, wherein he says:

"The Charleston jetties have been left low near the shore for the double purpose of economy in construction and to freely admit the flood tide to avoid reduction in the tidal prism. It is not unreasonable to believe that the quantity of dredging necessary and the quantity of sand that have been scoured seaward has been materially increased by sands driven over the low portion of the north jetty by the northeast storms. Such sand may be expected to be driven into the channel, usually over both jetties, if they are left low, even though the predominance of sand movement is in one direction."

This statement is undoubtedly correct and clearly recognizes one of the defects of twin jetties, submerged at their shore ends, and yet one of the officers recently in charge of that work stated officially:

"I have been out on that bar for thirteen years, day in and day out. . . . . I know that on top of those rocks there never was sandf . . . . I have never found it there." His contention being that it did not travel over the submerged ends of the jetties.

The value of this kind of evidence may be appreciated when it is remembered that the rock composing the inner end of the jetties is submerged and subject to the action of the breakers, so that no sand can lodge upon it as it is driven over. The history of the Charleston operations, covering more than twenty years, is too extensive to be further considered in this connection, but it has sufficed to cause the abandonment elsewhere of the submerged jetty theories of 1879.

5. Dredging.

Having reviewed the several methods of securing depths by auxiliary structures and by dynamite, the author concludes that:

"All things considered, in the present state of the science of bar improvement, dredging appears to be by all means the most economical and satisfactory method for such work at this place," because, as he adds, "the partial improvement of Brunswick bar by dredging, while it has been very expensive as to the rate per cubic yard, has been quite successful as to the permanence of the improvement."

The permanence of the channel is here attributed to dredging, and the effects of the dynamite are apparently ignored.

Had a straight channel been dredged through the bar at any time, it would soon have been obliterated; but instead thereof the integrity of the bar was disturbed by heavy charges of dynamite, while the dredge was used as an auxiliary to hasten the formation of the channel, which selected its own locus on curved lines. An inspection of the maps shows that the thalweg of the channel follows a reverse curve, having a trace similar to that of the plan of the reaction breakwater as designed for Aransas Pass. It indicates, therefore, the general form of the curve of greatest ebb energy in open water, and as such confirms the correctness of the theory of the reaction breakwater. The fact that currents move on curved lines is generally ignored in dredging operations with prejudicial results.

In considering the methods to be pursued at Galveston, the Board of 1886 reported: "The methods are (1) by dredging alone; (2) by using tidal scour between jetties, aided, if necessary, by dredging. As to the first method, it has already been tried unsuccessfully. . . . . There is not sufficient prospect of results commensurate with the cost of dredging being obtained and maintained to justify further experiment." The second method of twin jetties was therefore resorted to, but the tidal scour did not deepen the bar as expected, since the jetties were 7000 feet apart. Hence a cut was dredged along the axis of the channel. It was begun April 11, 1895, when the depths were about fifteen feet on the crest of the bar. But it did not remain straight, as the resultant drift soon swung the channel to the south on its normal curve, with a radius of five miles, and it now crosses the line of the south jetty produced. Many instances might be cited of the failure to secure channels in the open sea by dredging, especially where there is a prevailing littoral drift, but the fact is so generally recognized that it is not necessary to extend this discussion further than to add a few words as to cost.

It has been officially certified that the total cost of the work done by the contractor at Brunswick was $253,646.15 for a gain in depth of 5.6 feet, giving $45,293.95 per foot of depth secured. The author, however, states that dredging has been done on the Mersey bar at Liverpool for two and one-third cents per cubic yard, and says that fifteen cents is a fair price for this class of work. He then proceeds to estimate the quantity of material in place which it would have been necessary to remove to secure the present channel, and figures that 125,000 cubic yards at fifteen cents would have cost but $18,750 for the entire work, and that the actual cost of $253,646.15 was therefore excessive. He concludes: "The cost to the Government of all material removed, whether usefully removed or otherwise, has been $1.13 a yard, more than seven times the cost of ordinary dredging."

If it were only necessary to remove 125,000 yards to secure the channel, the cost would have been $2.03 per yard. At $1.13 there must have been 224,400 yards taken out, but as a matter of fact the actual cube of excavation was very much larger than this, since the enormous bank "which always moves very positively in one direction" was constantly supplying material to the channel.

The radical error in this computation of cost arises from regarding the volume of the material as a constant over a given area of the bar, and considering only the net loss or gain due to local changes in form of cross section. The absurdity of this method is seen from the table on page 14 of the report, wherein a strip 6370 feet long and of variable widths is taken for an estimate. I-

400 feet wide be used there is found to be a net fill of 77,000 cubic yards; for 600 feet width the fill is 113,000 cubic yards; for 800 feet it is 166,000, and for 1000 feet width it is 208,000 yards—in every case a fill, yet between the dates taken for this comparison the channel passing through this strip was deepened by dynamite, between April, 1891, and February, 1897, from 13.3 to 16.6 feet, a gain in depth of 3.3 feet.

Had the contractor been paid for excavation by place measurement for this area, therefore, he would have had to go into bankruptcy, since over 200,000 yards more were deposited than removed, and yet a deeper channel was created.

Moreover the dredging was not begun until August, 1896, and then it was merely to pump the material into the current until the fall of 1897, when bins were used to carry it out to sea, by which time the depths were increased nearly four feet. Even after this dynamite in 100-pound charges continued to be used, so that it is incorrect to regard this as a dredged channel when 168,000 pounds of explosives had been used to secure it.

Furthermore the report states (p. 17): "The north shoal has certainly been moving south for the last forty years. . . . . About 1,500,000 cubic yards have been added to its southern face since 1891." . . . . Also, "the north face of the south breakers . . . . has been scouring away correspondingly to the growth of the north shoal since 1857, and quite rapidly since 1888 (about 3,000,000 cubic yards and 1000 feet in width, scoured away between 1888 or 1890 and 1897 or 1900)." These admissions show large movements of bar material and an excess of about 1,500,000 cubic yards of scour during this period, and in the vicinity of dynamite operations, yet it is claimed that the deepening was "probably due to natural causes."

It would be a remarkable freak of nature that, with a bar drifting from north to south, there should have been a deposit of 1,500,000 yards on the one hand, and a scour of 3,000,000 yards on the other, between which a channel might have been dredged by the removal of 125,000 yards at a cost of $18,750, which would have been permanent, or else that "nature" should have concluded to reverse her machinery without apparent cause, and that, too, just at the time when dynamite was applied to the deteriorating bar, all for the benefit of a contractor who had previously undertaken to create a channel by the use of high explosives to save the port from ruin.

It may well be asked why no one had previously discovered that a channel could have been secured here for the petty sum of $18,750, and, if so, why it was not done instead of estimating millions of dollars for jetties and dredging plants, or why is not a permanent channel secured at other points on our alluvial coasts for similar trifling expenditures?

The fact is that this is not a dredged channel, but one secured by the effect of violent explosives on the bar which assisted the ebb currents to select and create the best path to sea, and no credit is given in the account to the large excess of material which was removed by such explosions. Any estimates, therefore, based on net measurements in place are utterly unreliable and the resulting price per unit is of no value in ascertaining the cost. The only reliable method is the cost per foot of depth actually secured, and on this basis the work has cost only about ten per cent. of that elsewhere, with far better and more permanent results. Hence dredging alone should not be recommended.

In a science necessarily so empirical as this it would seem that the best guide to results would be to make a careful diagnosis of the natural conditions and forces available, and then utilize them to the best advantage. This was the plan pursued at Aransas Pass, which is conceded to be the only instance of the kind on record; while the author would have it appear that it is fatally defective and is merely a case of two jetties. But no two jetties, so far as the writer's researches have gone, can be cited which have produced like results in practice with a tide of but fourteen inches, and with an obstructing wall across the bottom of the channel.

In conclusion, it would seem that of the several methods proposed for bar removal by the use of single or double jetties or by the reaction breakwater, the latter, so far as it has been tested, fulfills better than any other the conflicting requirements of harbor entrances, costs less than half as much and is far cheaper to maintain. Had this plan been adopted in 1888 it is believed, in view of subsequent events, that it would have saved the Government not less than $25,000,000 in the cost of jetty or breakwater construction and at least as much more (if capitalized) in the cost of maintenance, while the indirect benefits to commerce resulting from an earlier opening of our seaports for deep vessels would have exceeded the sum of both of these items.

The plan commends itself to Congress, but it does not seem to meet with favor from some of the junior officers of engineers charged with the improvement of our harbors, as is evinced by the report under discussion and the experience of the writer since the plans were first submitted to the Government for adoption, in 1888.

Stated Meeting, May 17, 1901.

Vice-President BARKER in the Chair.

Present, 30 members.

The donations to the Library were laid upon the table, and thanks were ordered for them.

The decease of the following members was announced :

Dr. Thomas Conrad Porter, of Easton, Pa., on April 27, 1901, aged 79 years.

Charles Swift Riché Hildeburn, of Philadelphia, at Bologna, Italy, on May 2, 1901.

Robert Noxon Toppan, at Cambridge, Mass., on May 10, 1901.

Mr. J. G. Rosengarten read a paper on "Franklin's Bagatelles."

Dr. R. W. Shufeldt presented a monograph on "The Osteology of the Accipitres."

Mr. Willcox made some remarks on some recent specimens of typography and the medium on which they are printed, which was discussed by Gen. Wistar.

The Society proceeded to an election for members, and the tellers reported that the following named candidates had been chosen :

Thomas Willing Balch, Philadelphia.

Hon. John B. McPherson, Philadelphia.

Prof. Dana C. Munro, Philadelphia.

Prof. Mazÿck Ravenel, M.D., Philadelphia.

Prof. Amos P. Brown, Philadelphia.